Compact UWB power divider packaged by using gap waveguide technology

Compact UWB Power Divider Packaged by Using Gap-Waveguide Technology

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Abstract—**We present the design of a new ultra-wideband (UWB) 3 dB power divider, packaged by using Gap Waveguide Technology. The power divider, a simple compact T–junction designed by using Klopfenstein taper technique, has a bandwidth of about 2–14 GHz, with the purpose of being used in a feeding network for the Eleven feed. Simulated and measured results of transmission and reflection coefficients are presented. Comparison of the power dividers between without packaging, packaged by a metal box and packaged with the gap waveguide technology has shown the superiority of the new design.**

Keywords-component; Ultra-wideband; Power Divider; Gap Waveguide; Packaging

I. INTRODUCTION

The Eleven antenna, having about 11 dBi directivity, constant beam width and a fixed phase center over a decade bandwidth [1]–[3], can be used as a feed for reflectors in ultra-wideband (UWB) radio telescopes, such as 1-10 GHz mid-frequency square kilometer array (SKA) [4] and 2-14 GHz VLBI2010 [5] radio telescopes.

The feeding network is always a critical part in the design of the Eleven antenna. Good UWB performance of a low reflection coefficient and low ohmic loss, a compact simple geometry and low cost make the design a real challenge.

One alternative of feeding networks for the Eleven antenna is to employ the UWB passive baluns [6], plus two UWB 3-dB power divider (or more accurately in our case, a power combiner), shown in Fig. 1. By this feeding network, the 4 differential ports of the Eleven feed are transformed to 2 single ended ports, one for each polarization.

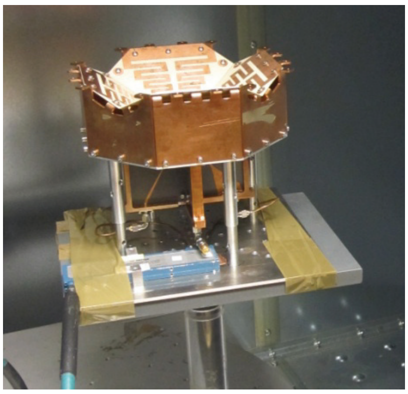

Fig. 1 Eleven Antenna with passive balun solution and power combiner

There exist commercially available power dividers to cover such a wide frequency range, such as 1–14 GHz Krytar power divider [7]. However, they suffer from high losses, specifically at high frequencies. For example, more than 1.2 dB ohmic loss at 7 GHz has been observed from the measurement of the Krytar power divider, shown in Fig. 2.

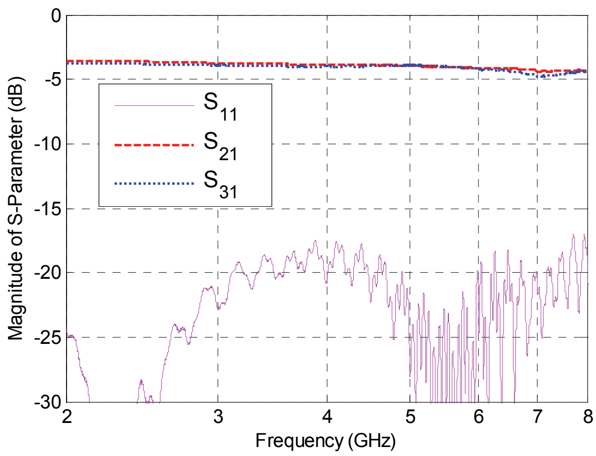

Fig. 2 Magnitude of the measured S-parameters of a Krytar power divider.

In addition to the high loss, the conventional packaging for UWB power dividers, simply enclosing the device in a metallic box, may also cause resonances. This will eventually degrade the performance of the whole system.

The purpose of this paper is to develop a small and low loss power divider with a bandwidth in the order of 10:1. By reducing the size, when it is enclosed in a metal box, the power divider may have resonances only at higher frequencies of the bandwidth. These resonances can then be suppressed by using the gap waveguide technology, constructed of a bed of nails [8]–[12]. Simulated and measured results shown in the paper have verified the design of the new power divider.

II. GEOMETRY AND DESIGN

The proposed power divider is based on a simple T–junction design, where 50 ohm microstrip line is divided into two 100 ohm lines. The T–junction discontinuity is compensated by a triangular notch. This structure has been optimized to achieve a minimum reflection coefficient. Then, a Klopfenstein Taper technique [13] is employed, to transform the 100 ohm microstrip lines to 50 ohm lines, as

$$\ln Z(z) = \frac{1}{2}\ln Z_o Z_L + \frac{\Gamma_o}{\cosh A} A^2 \phi\left(\frac{2z}{L} - 1, A\right), \quad for\ 0 \le z \le L$$

$$\phi(x, A) = -\phi(-x, A) = \int_0^x \frac{I_1\left(A\sqrt{1-y^2}\right)}{A\sqrt{1-y^2}} dy, \quad for\ |x| \le 1 \tag{1}$$

$$\Gamma_o = \frac{Z_L - Z_o}{Z_L + Z_o}, \qquad \Gamma_m = \frac{\Gamma_o}{\cosh A}$$

with a maximum ripple $\Gamma_m = 0.02$ in the pass band. $I_1(x)$ is the modified Bessel function. The pass band is defined as $\beta L > A$. Compared to other tapering techniques available for broadband matching, the Klopfenstein tapering provides an optimum solution providing a minimal reflection coefficient over an ultra-wide frequency band [13].

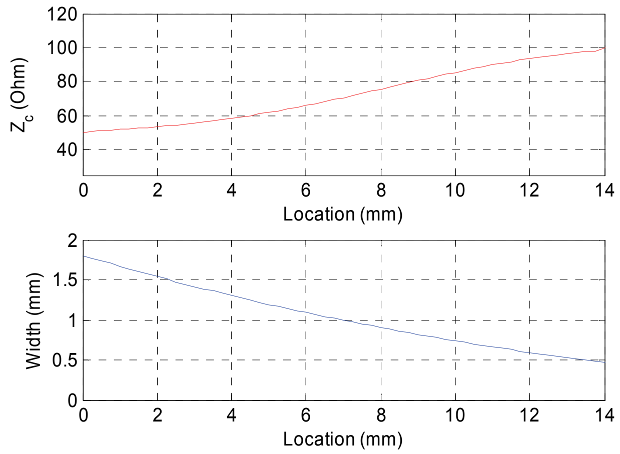

Fig. 3 Impedance value and its corresponding width of the microstrip line along the line length.

The tapered length of each arm of the power divider is chosen as 14 mm. Fig. 3 shows the variation of the impedance along the arm according to the Klopfenstein formula in (1). The corresponding width of the microstrip line on Rogers TMM3 board ($\varepsilon_r = 3.27$, thickness of 0.762 mm) along the arm is also shown in the Figure 3.

The packaging of the power divider has been done by using the Gap waveguide Technology, a bed of nails, in order to suppress the cavity resonances. The nails are realized by square-shaped metal pins, shown in Fig. 4. The pin's height is set to a quarter wavelength λ/4 at the center frequency of a band gap (no-cavity-mode band).

The typical no-cavity-mode bandwidth of gap waveguide technology is between 2:1 and 3:1, whereas the operating bandwidth of the new power divider is required in the order of 10:1, for feeding the Eleven antenna. Therefore, we use two methods to suppress the resonances.

First, the power divider is designed in a manner such that its size can be a minimum, which leads to a compact package box. A compact packaging box eliminates the resonances at low frequencies and then the resonances can only occur at high frequencies. In this work, we have designed the power divider with a size of 31.58 mm, and there is no resonance below 5 GHz.

Second, the gap waveguide technology is employed, with a bed of nails on the top cover to suppress the potential resonances from 5 to 15 GHz. The center frequency of the band gap of the gap waveguide is therefore 9.5 GHz. Fig. 4 shows the dispersion diagram for the case when pins are placed simply above on the substrate board. It is clearly shown that, with the presence of the pins, there is no other modes except for the dominate propagating mode existing in the packaging box within the band of 5–15 GHz.

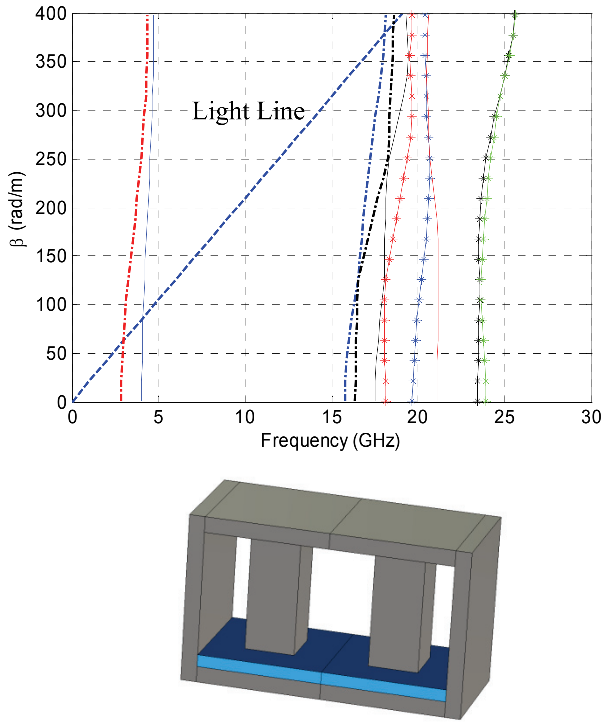

Fig. 4 Dispersion diagram of two row pin over the substrate material.

Fig. 5 shows the detail geometry of the proposed power divider. The ports impedance is 50 Ohms on all ports.

III. Simulated and Measured Results

In order to verify the design, a prototype was manufactured, where the pins and the metallic box were made by milling a copper plate, as shown in Fig. 6. Measurements were performed using a Vector Network Analyzer (E8363B PNA) from 1 to 13.5 GHz. All simulations are obtained by using CST MWS.

Figures 7–8 shows the simulated and measured reflection and transmission coefficients, when the power divider is enclosed in the packaging box with the top cover of the bed-of-nails. It can be observed that the power divider has a (over the band of 1–13.5 GHz) reflection coefficient of -10 dB and the transmission losses is about 0.5 dB at the maximum.

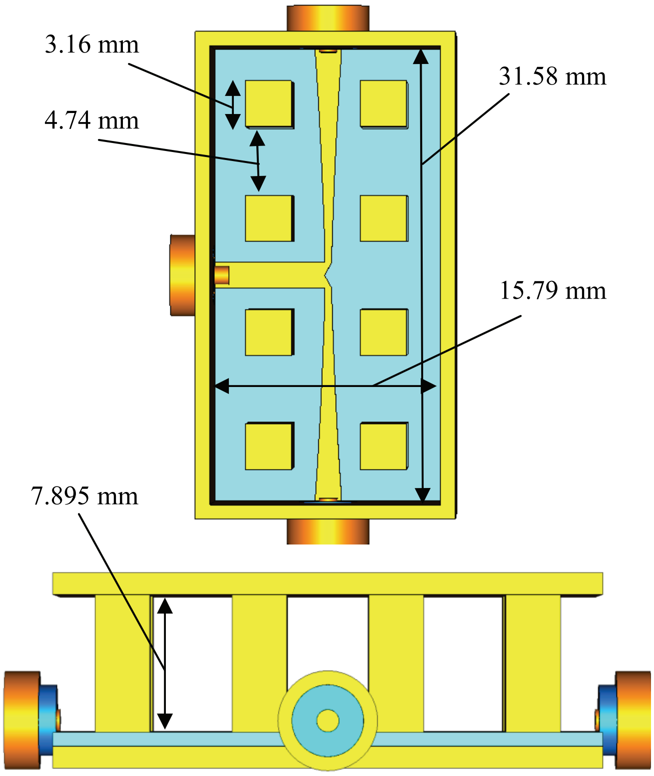

Fig. 5 Three Port power divider with pins around the divider.

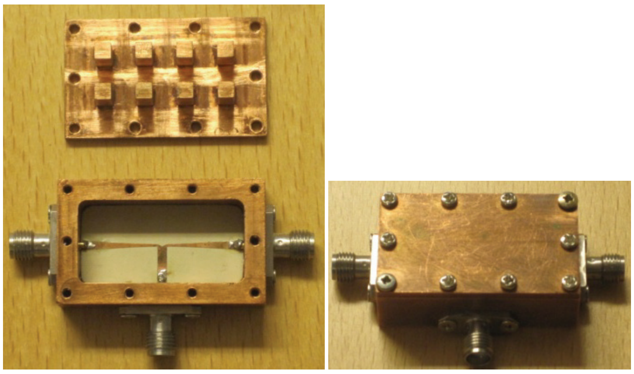

Fig. 6 Photo of the 1–13.5 GHz power divider with bed-of-nails.

The ohmic loss efficiency [14] of the power divider is calculated by

$$e_{ohmic} = |S_{11}|^2 + |S_{21}|^2 + |S_{31}|^2. \quad (2)$$

Fig. 9 shows the simulated and measured ohmic loss efficiency in the power divider due to the finite conductivity of the copper and the dielectric loss of the Rogers TMM 3 material.

Figures 10–11 shows the simulated and measured reflection and transmission coefficients, respectively, for the case when the power divider is simply enclosed in a metallic box without using the bed-of-nails. The results clearly show that without the bed-of-nails, a spike appear above 10 GHz. Those were the resonances which were suppressed by the lid-of-nails. Both simulated and measured reflection and transmission coefficients are good in agreement between 1–12 GHz. Although simulated results extend the behavior up to 13.5 GHz. This may be because of the mechanical inaccuracy in the milling process for the manufactured one.

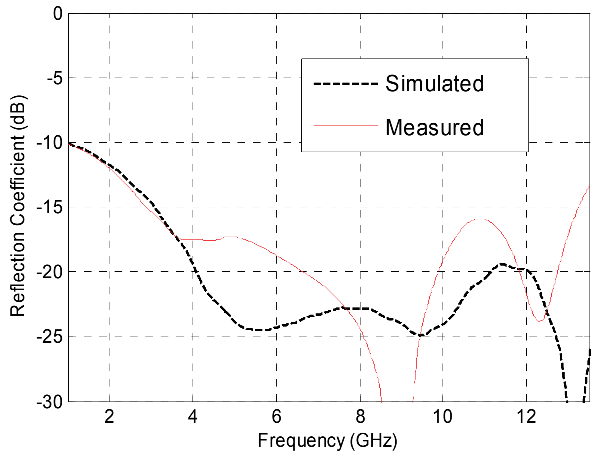

Fig. 7 Simulated and measured reflection coefficient of the power divider package with bed-of-nails.

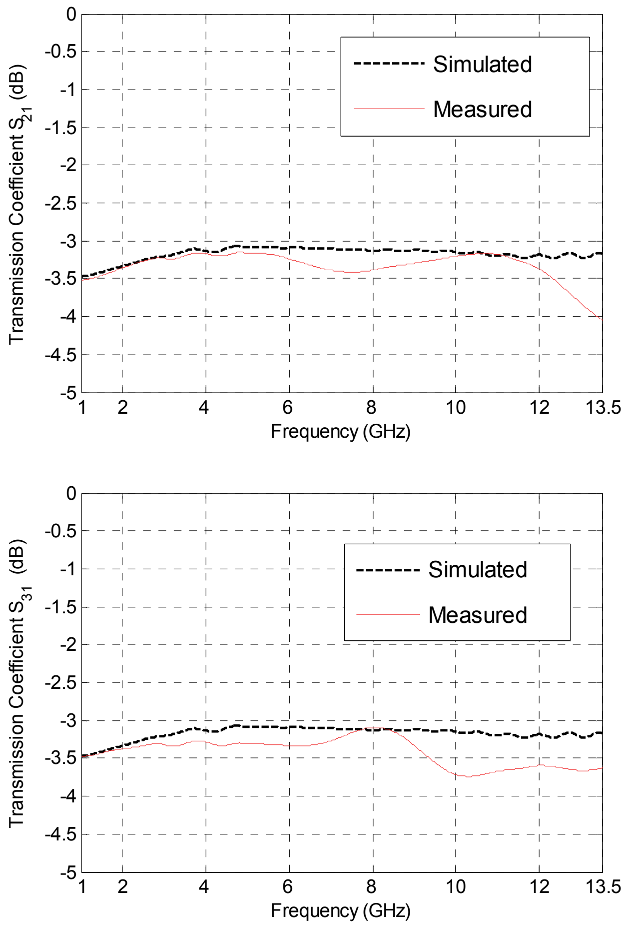

Fig. 8 Simulated and measured transmission coefficient of the power divider package with the bed-of-nails.

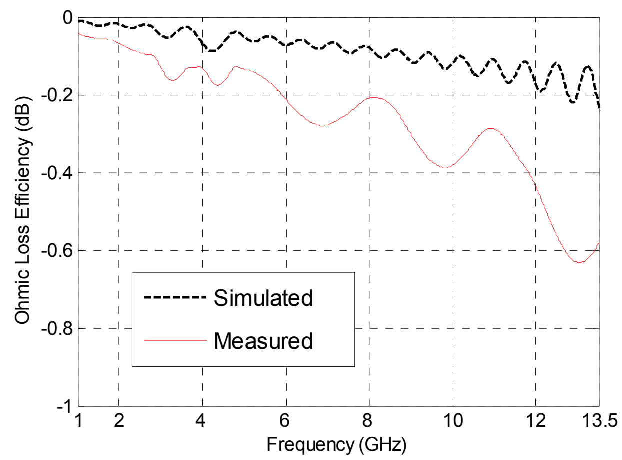

Fig. 9 Simulated and measured ohmic losses of the power divider.

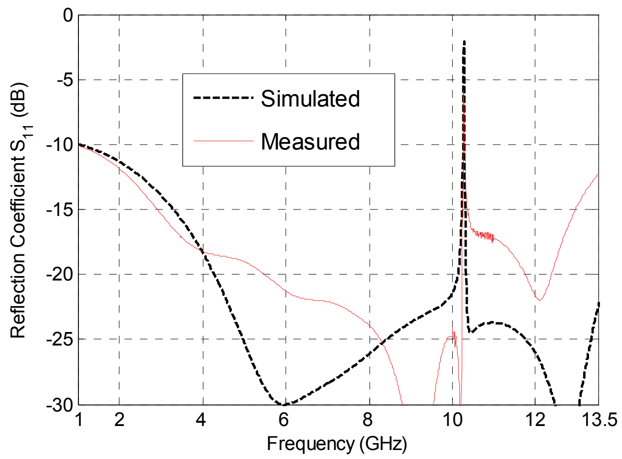

Fig. 10 Simulated and measured reflection coefficient of the power divider packaged by a metallic box without bed-of-nails.

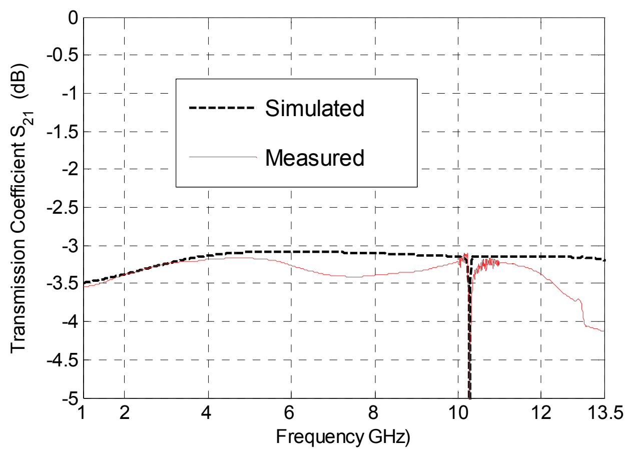

Fig. 11 Simulated and measured transmission coefficient of the power divider packaged by a metallic box without bed-of-nails.

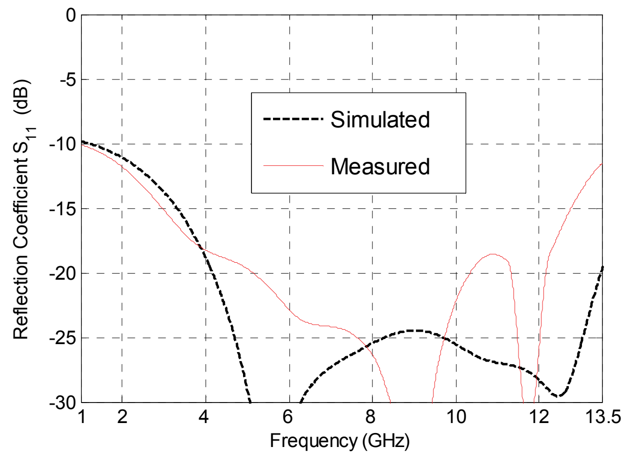

Fig. 12 Simulated and measured reflection coefficient, of power divider without enclosing it in box.

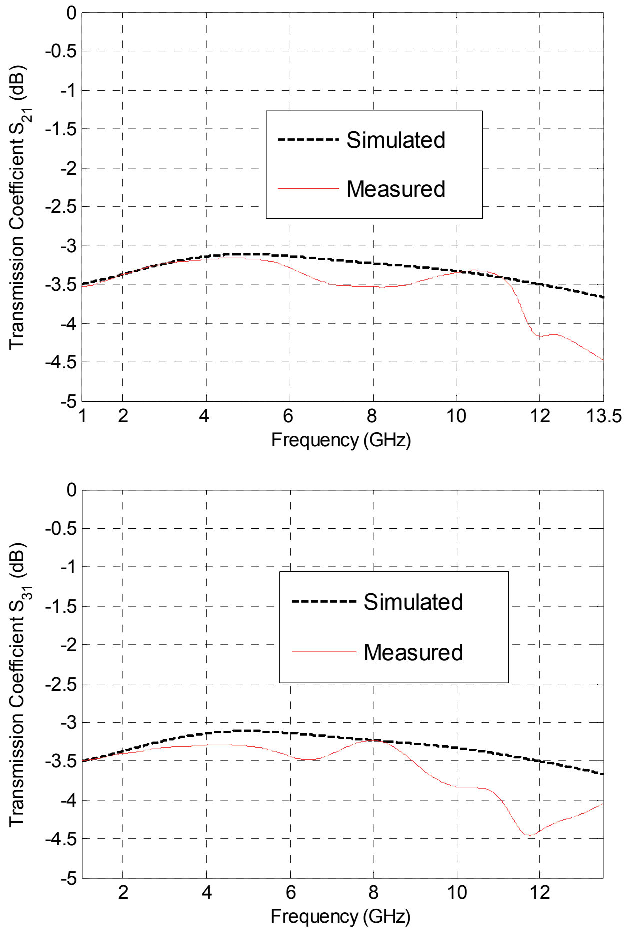

Fig. 13 Simulated and measured transmission coefficient, of power divider without enclosing it in box.

Similarly, Figures 12–13, shows the simulated and measured reflection coefficient and transmission coefficient, respectively, for the case when the power divider is not enclosed in the box. From the results, it can be infer that the difference between the simulated and measured results might be because of some asymmetry in the mechanical design of T – junction and the metallic box.

IV. CONCLUSION

UWB power divider packaged by using gap waveguide technology is presented in the paper. The Klopfenstein tapering technique has been employed to minimize the reflection coefficient and the bed-of-nails to suppress the resonance. The simulated and measured results are agreed well in the frequency band of 1–12 GHz having low loss. A better manufacturing tolerance will be emphasized in order to achieve the performance as good as the simulated one at the frequencies above 12 GHz.

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